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Development and Characterization of Gluten Free Pizza Crust from Rice, Maize and Sorghum Flours

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Rising rates of celiac disease and gluten intolerance have increased demand for gluten-free baked goods. This study developed gluten-free pizza crusts from rice, maize, and sorghum flours, comparing their properties to conventional wheat crust. Farinographic analysis showed rice flour absorbed the least water (54.77%) but had the longest development time (6.57 min). Texture analysis indicated the rice-based crust had the lowest hardness (38.03 N) and firmness (24.87 N), suggesting superior texture. Sorghum crust was darkest with the highest Chroma value (42.65). During 45-day frozen storage, all gluten-free crusts showed minimal changes in sensory and physicochemical properties. Microbial stability profiling revealed maize dough maintained the most stable pH and acidity, indicating enhanced spoilage resistance, while wheat dough acidified more. In conclusion, rice flour provided the most favorable rheological and textural properties, while maize offered superior microbial stability. Rice is recommended as a primary gluten-free base, with maize or sorghum as complementary ingredients to improve shelf-life and quality

Keywords: Celiac disease, gluten free pizza, sorghum, rice, rheology.

INTRODUCTION

The term "celiac" originates from the Greek physician Aretaeus of Cappadocia (1st century AD), who described patients with chronic bowel irritation and bloating. He named them "koiliakos," meaning "one who suffers in the bowels." Celiac disease is a non-preventable autoimmune condition, characterized by a chronic immune-mediated enteropathy in the small intestine. It occurs in individuals who are genetically susceptible and is triggered by the consumption of dietary gluten (Mcallister et al., 2019). The descriptive symptoms of celiac disease are the villous atrophy in the innermost layer of the small intestine (Perrotta and Guerrieri, 2022). Celiac patients have an inherited inability to digest gluten peptides found in wheat, barley, and rye (Scherf, 2019). Population-based studies indicated that celiac disease has a global seroprevalence of about 1%, while in Asian countries; the prevalence is lower, at approximately 0.5%**,** likely due to genetic, dietary, and diagnostic factors. The severity and death rate of disease among children is high in Pakistan, and the devastation could be high due to the surprisingly increasing rate of malnourished celiac patients. The estimated death rate of celiac children in Africa and Asia is largely due to insufficient knowledge about celiac disease and its management with a gluten-free diet (Buttet al., 2024; Gatti et al., 2024).Therefore, in order to alleviate the impact of celiac disease, it is essential to develop gluten-free alternatives utilizing naturally gluten-free grains. Adherence to a strict gluten-free diet (GFD) is considered the primary therapeutic approach for managing celiac disease (CD), as it effectively prevents the inflammatory response in genetically predisposed individuals.

The increasing demand for gluten-free products has encouraged significant research into developing bakery alternatives that match traditional wheat-based items in taste, texture, and nutrition, using innovative ingredients like alternative flours, binding agents, and fermentation techniques.Biscuit that is made of corn-flour (Lisovska et al., 2020), artichoke flour and supplemented with Jerusalem artichoke(Barakat et al.,2024), bread prepared with amaranth flour (Nasir et al., 2020), cake prepared with linseed, amaranth and bucket wheat (Niemira et al., 2024), cookies made with sorghum (Rai et al., 2014), bread prepared with

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rice, sorghum and cassava are a baked product that is present in the market.However,the consumption of these gluten-free products for a long time period can be directed to a nutritional imbalance in consumer. The avoidance of gluten-containing material from products refers to removing the major source of protein from the diet, as well as sticking to a high-carbohydrate diet that results in obesity, HDL levels increased (Demirkesen and Ozkaya, 2022). Therefore, in order to improve their nutritional quality, whole-meal GF cereals and pseudo-cereals with high nutritive value should replace the low-nutritional GF flours, and consequently, the technological processes would be optimized.

In the present study, cereal grain flours were used to develop a gluten-free pizza crust, incorporating a significant proportion of protein-rich ingredients. Historically, pizza originated in the Naples region of Italy. It was introduced to Brazil by Italian immigrants in the late 20th century and has since become one of the most popular foods in the country. Pizza consumption has increased rapidly since the 1970s, contributing significantly to the growing demand for sauces and cheese in the fast-food industry (Nowak et al., 2015; Campelo et al., 2017). Traditionally, pizza dough is made from wheat flour, which provides a strong gluten network that traps gas effectively and allows for superior dough extensibility and handling properties (Haridasan et al., 2025). To achieve acceptable dough characteristics in gluten-free formulations, various functional ingredients and additives are incorporated as wheat flour substitutes. These include flours from rice, sorghum, maize, quinoa, chickpea, buckwheat, and corn (Rocha Parra et al., 2015; Akesowan, 2016).

Gluten-free (GF) foods made from rice (*Oryza sativa*) offer distinct sensorial and nutritional benefits. Rice is particularly valued for its neutral flavor, hypoallergenic proteins, ease of digestion, and low sodium content. To enhance the nutritional and functional properties of GF products, alternative protein sources are increasingly being incorporated (Can Karaca et al., 2023). Recently, sorghum (*Sorghumbicolor*) flour has gained popularity among celiac patients as a partial or complete substitute for gluten-containing cereals. The inclusion of sorghum in gluten-free formulations has been shown to improve protein and mineral intake, benefiting both individuals with celiac disease and those following vegetarian diets (Hegde et al., 2023). Maize (*Zea mays*), another naturally gluten-free cereal, is also considered a safe grain for individuals with celiac disease. In cases where a corn-free diet is recommended, it has been observed that the overall reluctance toward adhering to a gluten-free diet (GFD) tends to decrease among celiac patients (Rai et al., 2014). Therefore, there is need to develop multipurpose gluten-free flour for celiac-patients.

The primary objective of this study was to develop gluten-free pizza formulations using rice, maize, and sorghum grains that are naturally free of gluten. Currently, there is no single, multipurpose gluten-free cereal-based formulation available in the food market that fully meets the dietary needs of individuals with gluten sensitivity. In response to this gap gluten-free flour compositionwas formulated that closely emulates commercial wheat-based flour and may therefore be used as 1-to-1 substitute to produce gluten-free baked product.

MATERIALS AND METHODS

***Procurement of raw material*:** Rice, sorghum, and maize were procured from a local retail market in Multan, Pakistan. All reagents and chemicals, including boric acids (99.5%), sulfuric acid (97%), sodium hydroxide, methanol, and sodium hydroxide (99.9%), were procured from BDH Chemicals (Shanghai, China) and Sigma Chemical Co., Ltd. (St. Louis, MO) from their local suppliers. Corn starch (Rafhan), potato starch (Bob's Red Mill), bread improver (eka-300), instant dry yeast (Baker's Dream), egg, salt, and sugar were procured from a local retail market in Multan, Pakistan.

***Proximate analysis of cereal flour sample*:** Rice, sorghum, and maize grain were cleaned, sorted, and dehydrated in a cabinet dryer (Pamico Technologies, Faisalabad, Pakistan) at 45 °C to a moisture level of 14 %. The dehydrated grains were converted into fine powder by using a kitchen grinder and aseptically stored in a glass jar for further analysis. Nutritional profile moisture (protocol#934-01), ash (protocol#942-05), fat (protocol#920-39), protein (protocol#984-13), fiber (protocol#978-10), carbohydrates and energy level of samples were examined by following the standard method of Association of Official Analytical Chemists 20th edition (AOAC, 2016).

***Development of gluten-free pizza dough formulations*:** This study aimed to formulate and compare gluten-free pizza dough based on rice (T1), maize (T2), and sorghum (T3) flour with a traditional wheat-based control (T0). A straight dough method was applied, involving the mixing, kneading, fermentation (35 ℃ for 60 minutes), and baking (200 ℃ for 20 minutes) of each dough. The control dough was prepared by using a simple mix of wheat flour, dry milk, and bread improver. Each gluten-free dough was prepared with 70 g of a primary flour (rice, maize, and sorghum), 40 g each of potato and corn starch, 5 g guar gum, and 7 g bread improver. Liquid ingredients included soy milk (80 ml) and egg white (30 ml) to enhance structure and moisture. Sugar and salt were reduced in the gluten-free sample to optimize the dough properties and flavor (Dobraszczyk and Morgenster, 2003).

***Sensorial Evaluation of gluten-free pizza*:** Freshly baked pizzas were subjected to sensory evaluation in the Food Analysis Laboratory of the Department of Food Science & Nutrition, FFSN, BZU, Multan. A panel of 25 trained tasters, aged between 18 and 54 years, all non-smokers and free from food allergies, participated in the assessment. Panelists were asked to evaluate the pizza based on several sensory attributes, including visual appearance, color (tinge), flavor,

texture, aroma, and overall acceptability, using a nine-point hedonic scale (Elia et al., 2011).

Table 1. Recipe for pizza formulations.

Ingredients	T_0	T_1	T_2	T_3
	Wheat	**Rice**	**Maize**	**Sorghum**
Flour(g)	150	70	70	70
Potato starch (g)	-	40	40	40
Corn starch (g)	-	40	40	40
Guar gum (g)	-	5	5	5
Yeast (g)	5	5	5	5
Sugar (g)	15	2	2	2
Salt (g)	2	1	1	1
Egg white (ml)	-	30	30	30
Soy milk (ml)	-	80	80	80
Bread improver (g)	3	7	7	7
Water (ml)	100	-	-	-
Dry milk powder (g)	5	-	-	-
Oil (ml)	20	20	20	20

Textural and Rheological Analysis if Gluten-Free Pizza Dough

***Determination of rheological properties of gluten-free flour*:** Farinographic parameters, including dough development time, water absorption, and dough stability, were determined by using the Brabender ® Farinograph (Brabender GmbH & Co. KG, Duisburg, Germany), following the method described by Demirkesen et al., (2010). Mixographic analysis, specifically missing time, was recorded using the Brabender ® Mixograph (National Manufacturing Co, Lincoln, NE, USA), in accordance with AACC method# No. 54-40 (AACC, 2000).

***Color profiling of gluten-free dough*:** Color profiling of the dough sample was analyzed using a ColorFlex TM colorimeter by following the working procedure of (Alviola and Monterde, 2018). The L*, a*, and b* color values were measured to assess the lightness and chromatic characteristics. The instrument was calibrated using a white standard, along with black and white calibration plates provided by the manufacturer. The L* value represented lightness, with 0 indicating black (shade) and 100 representing white (maximum lightness). The a* value indicated the red-green axis, where negative values represented green and positive values represented red. Similarly, the b* value denoted the blue-yellow axis, with negative values indicating blue and positive values indicating yellow.

***Texture Profile Analysis (TPA) of gluten-free dough*:** Texture Profile Analysis (TPA) was performed following the procedure described by Herrero et al., (2007), using an Instron Texture Analyzer (Model 3342, Instron EXTRA). Dough samples from selected trials were prepared with an approximate thickness of 25 mm and an apex of 9.7 mm. Each sample was subjected to a compression force using a cylindrical probe with a 30 mm diameter. The analysis involved a two-cycle compression test with a return time of approximately 10 seconds. The probe compressed the samples to 85% of their original height. Key texture parameters, including hardness, springiness, and firmness, were recorded to evaluate the mechanical properties of the baked gluten-free pizza dough.

***Storage stability analysis of frozen pizza dough*:** Rice, maize, sorghum, and wheat flour-based pizza dough were prepared, proofed, and stored at -18° C for stability profiling. The stability of formulated pizza bread was analyzed at 0, 15, 30, and 45-day intervals

***Determination of pH and titratable acidity*:** For the estimation of the pH of pizza doughs (rice, maize, sorghum, and wheat), the procedure from AACC, 2016 (02-52.01) was adopted. pH was recorded by using a pH meter (TS-PH200 model: ST3100, Ohaus corporation, Parsippany, USA). AACC, 2016 (method 02-31) was used for the determination of the acidity of formulated pizza dough. For titrable acidity, 1 ml of sample was mixed with 1 ml of distilled water, followed by titration with NaOH. During titration, 2-3 drops of phenolphthalein solution were added as an indicator.

Lactic acid content was calculated by following this equation.

Titratable Acidity % = $\frac{Vol.of\ NaOH\ used \times Normality\ of\ NaOH \times M.W\ of\ lactic\ acid}{Vol.of\ sample \times 1000}$ x 100

***Statistical Analysis*:** All experiments were conducted in triplicate, and the results were expressed as mean ± standard deviation (SD). Statistical analysis was performed using a completely randomized design (CRD) through analysis of variance (ANOVA). To determine significant differences among treatment means, the Least Significant Difference (LSD) test was applied at a significance level of $p \leq 0.05$. All analyses were carried out using Statistix software, version 8.1 (Tallahassee, FL, USA).

RESULTS AND DISCUSSION

***Nutritional Profiling of gluten-free cereal flour*:** The comparative analysis of the proximate composition of wheat (*Triticumaestivum*), rice (*Oryza sativa*), maize (*Zea mays*), and sorghum (*Sorghumbicolor*) revealed statistically significant ($p < 0.01$) variations in their nutritional profiles (Table 2). Sorghum exhibited the crude protein content (14.1 ± 1.1%), that was significantly higher than wheat (12.2 ± 0.9%), maize (9.5 ± 0.3%), and rice (7.9 ± 0.1%), suggesting its potential as a good plant-based protein source. Additionally, sorghum contained the highest crude fat (3.8 ± 0.3%), while rice has the lowest (0.5 ± 0.1%), reflecting differences in lipid metabolism among these cereals. In terms of carbohydrates, rice showed the highest concentration (78.2 ± 0.8%), consistent with its role as a high-energy staple, whereas sorghum had the lowest carbohydrate content (66.3 ± 1.4%), possibly due to its higher protein and fat

content. Crude fiber, an indicator of dietary fiber, was the highest in maize (3.4 ± 0.1%), which may enhance gut microbiota fermentation, while rice contained a negligible amount of fiber content, i.e., 0.4 ± 0.1%. The ash content, represented mineral composition was significantly greater in wheat, i.e., 1.9 ± 0.5% compared to the other grains, suggesting it has a richer micronutrient profile.

Moisture levels remained within a narrow range (11.3-12.4%), with rice having slightly higher hydration (12.4 ± 0.9%), possibly due to varietal or processing differences. These findings highlighted distinct nutritional compositions such as sorghum for protein and fat, rice for carbohydrates, maize for fiber, and wheat for balanced macronutrients and minerals. Such data are critical for formulating optimized diets, functional foods, and animal feed based on targeted nutritional requirements. In this study, the carbohydrate level of sorghum flour was lower than the reported value of 75%, used in pizza dough development (Camelo-Mendez et al., 2016). In line with our finding for rice nutritional composition, similar results were observed by Muttagi and Ravindra, (2020), who reported that rice flour contains protein (7.63-12.35%), fat (2.12-3.23%), ash (1.08-1.64%), moisture (8.44-10.04%), fiber (1.29-3.16%), carbohydrates (72.85-77.53%), and an energy value ranging from 353.16 to 366.91 kcal. In reference to the composition of maize flour, our findings were consistent with the results of Adeniyi and Ariwoola (2019), who reported that maize flour contains 1.93% ash, crude protein ranging from 9.32% to 15.75%, a significantly low crude fiber content of 0.86%, and a notably high carbohydrate content of 74.40%. The nutritional composition of sorghum observed in our study falls within the range reported by Tasie and Gebreyes, (2020), who found that sorghum flour contained moisture (9.66-12.94%), ash (1.12-2.29%), crude fat (2.48-4.60%), crude fiber (2.17-8.59%), crude protein (8.20-16.48%), and carbohydrates (67.56-76.42%). These findings confirm the nutritional consistency of these cereal flours and support their potential use in food product development.

Table 2. Nutritional profiling of cereal flours (Percentage on dry weight basis).

Component	Wheat	Rice	Maize	Sorghum
Moisture (%)	11.4±0.9^{b}	12.4±0.9^{a}	11.3±1.2^{b}	11.8±0.9^{b}
Crude fat (%)	1.6±0.3^{b}	0.5±0.1^{c}	1.2±0.3^{b}	3.8±0.3^{a}
Crude protein (%)	12.2±0.9^{b}	7.9±0.1^{d}	9.5±0.3^{c}	14.1±1.1^{a}
Carbohydrates (%)	70.9±1.1^{c}	78.2±0.8^{a}	73.5±0.5^{b}	66.3±1.4^{d}
Crude fiber (%)	1.9±0.2^{b}	0.4±0.1^{d}	3.4±0.1^{a}	1.8±0.2^{c}
Ash (%)	1.9±0.5^{a}	0.6±0.2^{c}	1.1±0.2^{b}	1.1±0.2^{b}

*Each mean value within the same row, followed by different letters is highly significant at 0.01 levels.

Textural and Rheological Analysis of Gluten-Free Flour and Pizza Dough

***Rheological properties of gluten free flour*:** The functional properties of the four cereal flours deployed significant variation in their water absorption capacity and dough characteristics (Table 3). Wheat flour exhibited the highest water absorption capacity (62.76%), followed by maize (57.87%), rice (54.77%), and sorghum (52.21%), indicating wheat's superior ability to hydrate and form dough. In terms of dough stability, wheat showed the strongest performance (10.58 minutes), while rice had the lowest stability (8.04 minutes), with sorghum (9.39 minutes) and maize (8.63 minutes) displaying intermediate values. Dough development time varied considerably among the cereals, with rice requiring the longest development time (6.57 minutes), followed by sorghum (5.41 minutes) and maize (5.16 minutes), while wheat had the shortest development time (4.39 minutes). The tolerance index, which reflects dough resistance to mixing, revealed sorghum flour as the most tolerant (14.05 BU), followed by maize (12.50 BU), with wheat and rice showed similar lower tolerance levels (9.50 BU and 11.35 BU, respectively).

Wheat flour exhibited superior functional properties, making it ideal for bread-making due to its high water absorption and dough stability. Gluten-free flours like sorghum, maize, and rice showed weaker dough characteristics because of the absence of gluten. Among them, sorghum and maize demonstrated better mixing tolerance and dough resistance, making them more suitable for use in blended formulations, while rice flour showed the poorest dough strength, requiring significant modifications for effective use (Cappelli et al., 2020). Gluten-free flours exhibited low hydration capacity, leading to poor dough cohesiveness and reduced stability under mechanical stress. Extended development and mixing times further compromise dough integrity. The addition of hydrocolloids like CMC and guar gum enhances water absorption, improves dough structure, and prevents moisture migration, thereby aiding gas retention and overall dough performance (Elkhalifa et al., 2007; Barcenas and Rosell, 2005).

Table 3. Farinogarphic profiles of wheat, rice, and maize and sorghum flour expressed as Brabender units (BU).

Flour	Water absorption (%)	Dough stability (min)	Dough development (min)	Tolerance index (BU)
Wheat	62.8±0.07^{a}	10.58±0.1^{a}	4.39±0.03^{c}	9.50±0.030^{c}
Rice	54.8±0.05^{c}	8.04±0.20^{d}	6.57±0.20^{a}	11.35±0.02^{c}
Maize	57.9±0.10^{b}	8.63±0.30^{c}	5.16±0.30^{b}	12.50±0.10^{b}
Sorghum	52.2±0.20^{d}	9.39±0.04^{b}	5.41±0.07^{b}	14.05±0.20^{a}

Each mean value within the same column, followed by different letters is significant at 0.01 levels

***Textural properties of gluten-free pizza*:** The textural analysis of pizza crusts made from wheat, rice, maize, and sorghum flours revealed significant differences in mechanical properties that can be attributedto their distinct compositional profiles (Fig. 1). Wheat-based crust (T0) exhibited the lowest hardness (24.64 N) and firmness (22.19 N) but the highest springiness (1.77 mm), characteristic of gluten's viscoelastic network that provides structural flexibility. In contrast, sorghum crust (T3) demonstrated markedly greater hardness (61.49 N) and firmness (29.59 N) alongside reduced springiness (1.26 mm), reflecting its gluten-free composition where rigid starch granules and dietary fiber create a more compact, less elastic matrix. Rice crust (T1) ranged between wheat and sorghum in hardness (38.03 N) and firmness (24.86 N), with moderate springiness (1.64 mm), while maize crust (T2) resulted in closer to sorghum in hardness (52.97 N) and firmness (26.67 N) but retained slightly better springiness (1.58 mm).

The intermediate textural properties of rice and maize pizza crusts reflect their unique starch gelatinization behaviors, with maize showing greater mechanical resistance due to higher amylose content, and rice offering a balance of firmness and elasticity. These results highlighted the importance of biopolymer interactions, gluten proteins in wheat enable elastic deformation, while non-gluten systems rely on starch retrogradation and fiber reinforcement, resulting in firmer, less elastic structures (Shoukat et al., 2025; Chin et al., 2011). Among gluten-free options, rice flour stands out due to its neutral flavor, smooth texture, and high amylopectin content, which promotes better gel formation and dough cohesiveness without brittleness. Its superior water absorption and compatibility with hydrocolloids enhance elasticity and gas retention, narrowing the functional gap with wheat-based dough (Park and Kim, 2023; Muhammad et al., 2024). While all gluten-free flours lack the viscoelasticity of structural integrity, hypoallergenic nature, and broad consumer appeal.

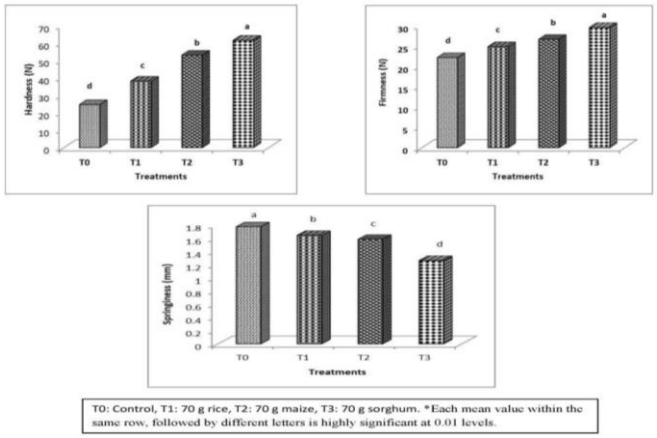
Hardness (N)
Firmness (N)
Springiness (mm)
Treatments
T0
T1
T2
T3
T0: Control, T1: 70 g rice, T2: 70 g maize, T3: 70 g sorghum. *Each mean value within the same row, followed by different letters is highly significant at 0.01 levels.

Figure 1. Effect of grains on textural properties of baked pizza dough.

***Color evaluation of gluten-free pizza*:** The study compared the color characteristics of pizza dough made from wheat, rice, maize, and sorghum flours using the CIELAB color space (L, a, b) and Chroma. Wheat-based pizza exhibited the highest lightness (L = 71.75 ± 0.39), making it the lightest in color, while rice-based dough (L* = 68.41 ± 0.68) and maize-based dough (L* = 68.87 ± 0.40) were significantly darker. Sorghum-based dough (L* = 69.40 ± 0.27) showed intermediate lightness. In terms of redness (a), sorghum pizza dough had the highest value (2.95 ± 0.06), followed by maize pizza dough (2.13 ± 0.04) and wheat (2.09 ± 0.11), whereas rice pizza dough (1.43 ± 0.08) displayed the least redness, appearing more greenish. Yellowness (b) was most pronounced in sorghum flour dough (26.71 ± 0.17), followed by maize flour dough (24.52 ± 0.10) and wheat flour dough (23.46 ± 0.17), while rice flour dough (16.12 ± 0.60) had the lowest yellowness. Chroma, representing color saturation, was highest for sorghum four dough (26.87 ± 0.16), indicating the most vivid color, followed by maize flour dough (24.61 ± 0.09) and wheat flour dough (23.56 ± 0.18), with rice flour dough (16.18 ± 0.60) being the least saturated. These differences likely due to the variations in natural pigments present in each flour, such as anthocyanins in sorghum and carotenoids in maize, influencing the final appearance of the pizza bases.

Overall, sorghum-based pizza had the most intense and vibrant color, while rice-based pizza was the darkest and least colorful. The color result revealed that rice pizza had light white color tendencies that emulate wheat pizza. Color assessment is a multifactorial phenomenon. Concurrently, the colors of baked products are also linked with browning. Maillard reaction and caramelization are forms of non-enzymatic browning that contribute to the darkness in the product (Hellwig et al., 2014).

Table 4. Color analysis of gluten free pizza baked-dough.

Pizza	L*	a*	b*	Chroma
T0	71.75±0.39^{a}	2.09±0.11^{b}	23.46±0.17^{c}	23.56±0.18^{c}
T1	68.41±0.68^{c}	1.43±0.08^{c}	16.12±0.60^{d}	16.18±0.60^{d}
T2	68.87±0.40^{c}	2.13±0.04^{b}	24.52±0.10^{b}	24.61±0.09^{b}
T3	69.40±0.27^{b}	2.95±0.06^{a}	26.71±0.17^{a}	26.87±0.16^{a}

T0: Control, T1: 70 g rice, T2: 70 g maize, T3: 70 g sorghum. Each mean value within the same column, followed by different letters is highly significant at 0.01

***Sensory evaluation*:** The sensory evaluation of pizza samples made from wheat, rice, maize, and sorghum flours revealed significant differences in appearance, taste, aroma, texture, and overall acceptability (Table 5). Rice-based pizza scored the highest in appearance (8.4), followed by maize (7.9), wheat (7.5), and sorghum (6.2), with statistical significance ($p < 0.01$). Panelists rated rice pizza as the most visually appealing, while sorghum pizza received the lowest scores, likely due to its darker and more intense color, which may not

align with consumer expectations. According to Leon et al. (2006), color plays a crucial role in food acceptance, and the recorded color scores (wheat: 7.6, rice: 8.4, maize: 7.4, sorghum: 6.3) further confirmed rice pizza's superior visual appeal.

In terms of taste, rice pizza again led with a score of 8.4, closely followed by wheat (7.3) and maize (7.4), while sorghum pizza (6.4) was perceived as slightly bitter. Similarly, for aroma, rice pizza scored highest (8.2), with wheat (7.1) and maize (7.4) performing well, whereas sorghum (6.3) was less preferred. Maize pizza competed closely with traditional wheat pizza in taste and aroma, suggesting its potential as an alternative. Texture is a critical factor in pizza quality, particularly for gluten-free variants. Rice pizza (8.5) scored higher than wheat pizza (7.2) in texture, likely due to hydrocolloids improving moisture retention and structural stability. Maize pizza (7.4) had a moderate texture, while sorghum pizza (6.0) was deemed grainy and crumbly. Overall acceptability was highest for rice pizza (8.5), followed by maize (7.7) and wheat (7.7), while sorghum pizza (6.2) was least preferred due to inferior taste and color. These findings suggested that rice flour is the best gluten-free alternative to wheat flour, offering superior sensory properties, mild flavor, and digestibility. Additionally, rice flour's hypoallergenic nature and low prolamin content (2.5-3.5%) make it suitable for gluten-sensitive consumers (Gujral and Rosell, 2004). Maize flour also showed good acceptability, whereas sorghum pizza requires further refinement to improve its sensory appeal.

For gluten-free pizza production, rice flour is the optimal substitute for wheat flour, delivering excellent appearance, taste, and texture. Maize flour is a viable secondary option, while sorghum-based pizza needs modifications to enhance its acceptability. These insights can guide product development for gluten-intolerant consumers seeking palatable and visually appealing alternatives.

Table 5. Sensory evaluation of gluten free pizza formulations.

	Treatment			
	T_0	**T_1**	**T_2**	**T_3**
Appearance	7.5 ± 0.5^{b}	8.4 ± 0.3^{a}	7.9 ± 0.5^{ab}	6.2 ± 0.2^{b}
Color	7.6 ± 0.5^{ab}	8.4 ± 0.2^{a}	7.4 ± 0.8^{ab}	6.3 ± 0.1^{b}
Taste	7.3 ± 0.3^{b}	8.4 ± 0.2^{a}	7.4 ± 0.5^{ab}	6.4 ± 0.4^{ab}
Texture	7.2 ± 0.3^{ab}	8.5 ± 0.1^{a}	7.4 ± 0.3^{b}	6.0 ± 0.2^{ab}
Aroma	7.1 ± 0.2^{b}	8.2 ± 0.2^{a}	7.4 ± 0.4^{b}	6.3 ± 0.1^{b}
Acceptability	7.7 ± 0.2^{ab}	8.5 ± 0.1^{a}	7.7 ± 0.3^{ab}	6.2 ± 0.1^{b}

T_0: Control, T_1: 70 g rice, T_2: 70 g maize, T_3: 70 g sorghum. *Each mean value within the same column, followed by different letters is significant at 0.01 levels.

Storage Stability Analysis of Frozen Pizza-Dough

***Effect of storage over pH and Acidity level of pizza-dough*:** The pH levels of pizza dough made from different flour types (wheat, rice, maize, and sorghum) were monitored over a 45-day storage period to evaluate their acidification patterns and microbial stability (Table 6). Initial pH measurements at day 0 showed that all dough samples had statistically similar pH values ($p>0.05$), ranging from 5.01±0.11 (wheat) to 5.42±0.06 (maize). During storage, wheat-based dough exhibited the most pronounced acidification, with pH decreasing significantly ($p<0.05$) from 5.01 to 4.87 by day 45, suggesting active microbial fermentation. Rice dough showed moderate acidification, declining from 5.25 to 5.11, while sorghum dough followed a similar trend (5.37 to 5.22). Notably, maize dough maintained the most stable pH profile throughout storage (5.42 to 5.39), indicating minimal microbial activity and superior shelf-life potential.

The study examined the acidity development in pizza dough prepared from wheat, rice, maize, and sorghum flours during 45 days of storage. Initial lactic acid levels were comparable across all samples, ranging from 0.06% to 0.08%. However, distinct acidification patterns emerged during storage. Wheat dough exhibited the most pronounced increase in acidity, rising significantly ($p<0.05$) from 0.08% to 0.11%, suggesting active microbial and enzymatic activity. Rice dough showed more moderate acidification by lactic acid content, increasing from 0.07% to 0.08%, while maize dough demonstrated remarkable stability with only a slight rise from 0.06% to 0.08%. Sorghum dough followed an intermediate pattern, increasing from 0.06% to 0.09%.

The observed pH and acidity changes during storage closely align with microbial count data, confirming that maize-based pizza dough exhibited superior microbial stability compared to other flours. These acidification patterns likely result from differences in flour composition, including fermentable substrates, buffering capacity and natural antimicrobial compounds. Maize flour appears to inhibit acid-producing microorganisms, resulting in minimal pH decline and limited acidity increase, making it a strong candidate for gluten-free pizza products requiring extended shelf life. In contrast, wheat and sorghum dough showed more pronounced acidification, indicating the potential need for pH-modifying additives or preservatives to maintain product quality during storage. The initial drop in pH, particularly in wheat dough, was attributed to CO_2 release during fermentation, forming carbonic acid which later stabilized (Janssen et al., 2021; Thiele et al., 2002). Gluten-free dough exhibited less pH change due to lower gas production and weaker fermentation. Wheat flour's higher responsiveness to acidic conditions also led to stronger acid-protein interactions, influencing protein charge and dough structure (Schefer et al., 2021).Despite these changes, all dough samples maintained pH levels within the optimal 4-6 range for yeast viability. Nonetheless, prolonged frozen storage may negatively impact yeast activity due to solute concentration, ionic toxicity, and reduced glycolytic enzyme function, ultimately compromising dough performance (Aminlari et al., 2002). These findings offered

critical insights for formulating stable, high-quality gluten-free pizza products, with maize flour emerging as a particularly promising base

Table 6. Effect of storage days at -18°C, over pH of gluten free pizza dough.

Time	Treatment			
(days)	T_0	T_1	T_2	T_3
0	5.01±0.11^{a}	5.25±0.08^{a}	5.42±0.06^{a}	5.37±0.09^{a}
15	4.91±0.04^{ab}	5.12±0.07^{b}	5.42±0.03^{a}	5.34±0.06^{ab}
30	4.90±0.06^{ab}	5.11±0.04^{b}	5.41±0.03^{a}	5.29±0.02^{ab}
45	4.87±0.07^{b}	5.11±0.06^{b}	5.39±0.03^{a}	5.22±0.09^{b}

T_0: Control, T_1: 70 g rice, T_2: 70 g maize, T_3: 70 g sorghum. Each mean value followed with different letters in same column is statistically different ($p \leq 0.05$)

Table 7. Effect of storage days at -18°C, over acidity of gluten free pizza dough.

Time	Treatment			
(days)	T_0	T_1	T_2	T_3
0	0.08±0.002	0.07±0.003^{b}	0.06±0.003^{a}	0.06±0.002^{b}
15	0.09±0.002	0.08±0.002^{b}	0.07±0.003^{a}	0.07±0.003^{ab}
30	0.09±0.003	0.08±0.003^{ab}	0.07±0.003^{a}	0.08±0.004^{a}
45	0.11±0.004	0.08±0.006^{a}	0.08±0.006^{a}	0.09±0.004^{ab}

T_0: Control, T_1: 70 g rice, T_2: 70 g maize, T_3: 70 g sorghum. Each mean value followed with different letters in same column is statistically different ($p \leq 0.05$).

***Conclusion*:** This study comprehensively evaluated the physicochemical, textural, sensory, and storage stability characteristics of gluten-free pizza dough formulated using rice, maize, and sorghum flours, compared with conventional wheat-based dough. Among the tested flours, rice flour emerged as the most promising gluten-free alternative, exhibiting favorable rheological properties, low dough hardness, good springiness, and excellent sensory acceptability. Although rice flour absorbed less water, its dough showed higher development time, and the resulting baked crust had a soft, cohesive texture that closely resembled traditional wheat-based pizza. In contrast, sorghum and maize dough displayed higher hardness and lower springiness, affecting their overall acceptability.

In terms of storage behavior at -18°C, maize-based dough demonstrated the highest microbial and chemical stability, with minimal changes in pH and acidity over time, indicating its potential for extended frozen storage without quality deterioration. Sorghum crust exhibited the most intense coloration due to its higher phenolic content, while rice maintained a more neutral appearance suitable for mainstream consumers. Overall, rice-based pizza proved to be a strong candidate for gluten-free product development, offering an appealing balance between texture, flavor, and shelf life. However, the findings also highlight the need for further innovation in composite flour formulations using rice with other gluten-free cereals to enhance nutritional content, functional behavior, and protection against celiac disease.

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***Conflict of interest*:** The authors declare that they have no conflict of interest.

***Ethical statement*:** This study did not involve human or animal subjects, and therefore did not require ethical approval.

***Availability of data*:** The datasets generated and analyzed during this study are available from the corresponding author upon reasonable request.

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***SDGs addressed*:** Good Health and Well-being, Industry, Innovation and Infrastructure, Responsible Consumption and Production.

***Policy referred*:** National and Global Celiac Disease Management Policies; Food Safety and Allergen-Free Labeling Policies; Nutrition Policy for Special Dietary Needs.

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